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RECENT RAILWAY ECONOMIES

Paper Read Before the Society of Engineers of the University of Minnesota,

BY

EDWIN E. WOODMAN

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RECENT RAILWAY ECONOMIES.

BY EDWIN E. WOODMAN.

A late news item recounted the discovery of a burning coal bed in Wyoming, and there is little doubt that the incident was only the most recent of many re-discoveries of the same thing that I saw at the head of Little Powder river thirteen years ago, when examining the Black Hills country for a railway line and to report on its natural resources. At that time the geological insularity of the Hills, as an outlier of the Rocky Mountains, was matched by the isolation of the people, who were two hundred miles from the nearest railroad, possessed of a Sancho Panza's Island in the midst of the Great Plains. I went a hundred miles west of Deadwood with a guide, riding in a light buckboard, to examine an exposure of lignite. We found the half-formed coal showing twenty feet of thickness, where a creek had made a shallow valley, and at this deepest place it was on fire and had been burning an indeterminable time. We fried our bacon and boiled our coffee on the glowing edge of this Inferno, and as I lay at night on the ground, with feet to the heat, in the midst of a vast solitude, and looked up to a few friendly stars, whose acquaintance always relieves me from the sense of loneliness when in uninhabited places, and somehow co-ordinates the universe, it was not impossible to guess at the grand scale of those operations of nature that resulted in this enormous bed of fuel. The old cosmogony, of which man and his home were the center, would have made all this for the very purpose of comforting the vagrant engineer. But Galileo, with the first feeble telescope, pierced that fog of error and proved that finite relations and adaptations do not really make clear any designs of the Infinite. But here was this exposure of lignite, five hundred miles intermediate between two similar beds known on the Northern Pacific and Union Pacific railways. It was then a probable inference

that it extended across the entire one thousand miles, and this opened broadly to the mental view the state of that young world in which peculiar and adequate causes were effective to such vast results.

The geologist and the chemist have delighted us with the natural history of a lump of coal. Igniting it as it were by the fire of the imagination, they have made it glow for us with the light and the heat of a sun "before time was," of ages long antecedent to man, the clock-maker. They have clothed that ancient globe with a luxuriance of vegetation far surpassing the tangles of the Amazon, peopled it with corresponding animal monsters; and when I broke out pieces of the lignite in which the bole, the knots, the bark, the grain of the wood, were almost as palpable evidences of the tree as like parts would identify the allied tamarack of to-day, the vast swamps in which this immense deposit of half carbonized wood accumulated were conceived with the same strength as the ancient civilization of the Nile valley is now apprehended, when we look upon the photograph of Rameses, the very Pharaoh who persecuted the Hebrews. The imagination has indeed notably played its part in science. It is a kind of sublimated reason, by which truths now beyond the range of demonstration are gained by a leap and held till the slower faculty can slide a cantilever over the gap. It has also been a powerful instrument of invention, and the chief aid in effecting those ameliorations of the physical conditions of life in our world on which all other forms of progress depend. Doubtless the cave dweller brooded over the problem of how he could subdue the mammoth and make it carry wood for his fire. For in after ages he accomplished it in India, meantime improving his weapons and tools from flint to copper, to bronze, to iron, to steel, ever further subjugating the hostile forces of the world. With the rise of intellect brute forces appear more and more to have declined, as if man was ever the integration of all that had gone before; though far weaker physically, yet able to cope with the same obstacles by a higher method, which we may typify by the lever. In due time he thought out his steam engine, by which he brought back the mighty saurians, harnessed them to tread-mills the world over, and trained pterodactyls to fly in lines at fifty miles an hour, pulling the limited. And so we come to our theme of the railroad.

Next to the invention of the steam engine, that of the railway has done most of our material welfare; and next again the Bessemer process, by which both of the others have been so vastly amplified in their utilities, may be given rank. Using this term to cover all the improvements by which steel has been made so much better and cheaper, we may affirm that the enormous increase of wealth shown by many countries, including our own, is primarily due to the success of this invention, of which it was long since said: "It has been of more value than all the gold of California." In forty years our constructive arts have been revolutionized by it. Whereas, forty years ago, iron was too costly and unreliable to be much used by the engineer, and steel was entirely beyond his reach, twenty years since the new metal had not only superseded iron for most constructive purposes, but at a saving to mankind of five thousand millions of dollars, computed on the total product and the diminished cost. To the date of this invention we refer the introduction of improved heavy machinery, steel vessels, heavy ordnance, armor plates and modern projectiles, the widespread use of rolled forms in architecture and bridge construction; while it would be well-nigh impossible to enumerate all the present uses of steel, which from its superior strength and ductility, comparative lightness, uniformity of quality, and adaptability to special requirements, has finally almost driven iron from the engineering field. The most admirable and useful point of difference between this metal and iron is, that the fibrous structure of iron has in steel given place to a homogeneous molecular arrangement, so that, as Sir William Siemens described it, "it has its full strength in every direction."

The most extensive and useful application of the Bessemer metal has been in the improvement of railways, chiefly in the track, though otherwise largely in the related structures of bridges and buildings, and in machinery and rolling stock. The locomotive was the first essential of a steam railroad, the track the second; but soon these conditions were reversed, the track having become the more difficult to maintain with the requisite economy. The Rocket weighed two and one-half tons, our present engines weigh sixty tons. The former carried 2,500 pounds on each driver, the latter carry over 20,000, and these differences are a fair index of the economy of using

steel. Since the introduction of this material the improvement of our railways, the great increase in their mileage and the corresponding development of our national wealth have severally been very great, and may be traced to the possession of this metal. The tendency of railway economies along mechanical lines during the last twenty years, by which these results have largely been obtained, has been controlled by the Bessemer process.

The first Bessemer rails introduced into this country from England cost one hundred and fifty dollars a ton. Like rails of our own make have recently been sold at seventeen dollars a ton. Sir Henry himself, while in the first flush of his success, and amassing a fortune, immediately reduced the cost of tires in England from four hundred and fifty dollars a ton to one hundred. A Bessemer rail will last from six to nine times as long as an iron one under the same traffic. Here is a clew to many economies. With the life of rails so greatly prolonged, the cost of renewal of rails and repairs of track, a heavy item of expense to every company, is of course greatly reduced. From being able to obtain rails at once cheaper and far more durable, other important consequences have flowed. Heavier rails have been placed within reach. This in turn has made possible the use of heavier engines, stronger cars and heavier loads, resulting in such economies of operation as to be a principal cause of the continual decline in freight rates in this country, which to-day are only a third of what they were when the new metal had become fairly introduced.

If an engine of new model proves to be twice as serviceable in tonnage hauled as one of the kind previously used, then half as many trains, drawn by such new engines, will do the same business. This will chiefly apply to through traffic, because local traffic usually does not make long trains, or at all events the same degree of economy can not be worked in it, since heavy engines can not so frequently be loaded to their full capacity in local business as in through traffic. The most obvious reduction in expenses due to the new engines will be, a certain number of train crews dispensed with. Also, there may be economy in fuel, the general rule being that large boilers and engines use fuel to better advantage than small ones. I may illustrate this by recent experience. The freight traffic of the C., St. P., M. & O. Railway Company during October, 1896, was the heavi-

est in the history of the road. As a consequence of this, engines were loaded to their full capacity, and the engine performance became especially interesting. Following are the mileage and coal consumption of three classes of engines:

Cylinders.	Miles run.	Tons coal used.	Pounds coal per train mile.
17 by 24	133,750	6,245	93.4
18 by 24	149,400	6,853	91.7
19 by 24	54,664	3,014	110.3

It has not been practicable for me to obtain the tons hauled by these engines. But assuming that they were fully loaded, which we may do in consideration of the deficiency of cars under the unusual demand, a comparison of these engines in respect to consumption of fuel may be reached by dividing the quantity of coal consumed per train mile by the adhesive weight, or weight on the drivers, since this weight is closely proportional to the hauling capacity, and in the present case to the number of tons hauled. Applying this test, we find that the relative consumption of coal per ton mile is, for the 17 by 24 cylinders, 20; for the 18 by 24 cylinders, 16; for the 19 by 24 cylinders, 11; or, the largest shows an economy of 45 per cent over the smallest in the item of fuel consumed per ton mile.

Another illustration may be drawn from passenger service in the same month. The new express locomotives used on the Chicago limited have cylinders 19 by 24, drivers 73 inches, and weigh 126,000 pounds each. The engine and tender and supplies of fuel and water weigh 113 tons. If we add to the last mentioned weight the weight of the cars that compose one of these trains, and of the several items comprised in the load, we shall find that the average number of tons moved per train mile is 456. In October, 1896, twin engines in this service together ran 17,015 miles and consumed 746 tons of coal. From these data it follows that these engines moved a ton a mile by the consumption of 19-100 of a pound, or 3 ounces, of coal. The card time of this train, covering a distance of 200 miles, is 31 miles per hour, and the actual speed between stations often 40 to 50 miles.

In comparison with this we take the Stillwater run, with engine and tender weighing 58 tons, and cars 57 tons. These trains made 5,840 miles in October, with the consumption of 170 tons of coal, showing that it required half a pound of coal to move a ton a mile, or 8 ounces as against 3 in the case of

the limited, and at lower speed. Part of this difference is undoubtedly due to the relative preponderance of engine friction in the second case. It is no doubt true that the lighter engine could take a heavier load and yield a better result per ton mile than it did in this case.

Three ounces of coal seems a small quantity to move a ton a mile by any kind of mechanism, yet it is well known that the locomotive is a form of engine comparatively wasteful in the use of fuel. Bituminous coal is used in operating the trains under consideration, Spring Valley, from Illinois, in running north, and No. 8 Pittsburg, from Pennsylvania, in running south. For the purpose of illustrating fuel economy, I have selected a distance of 4.55 miles in which no stops are made by these trains, the time allowed being seven minutes with the grade and eight against it. The average speed is 36½ miles per hour, and the average of the rise and fall 66 feet, corresponding to a grade of 14.5 feet per mile for the whole distance. I neglect the effect of a little light curvature. Using Clark's formula for train resistance, and comparing the foot-pounds exerted by the engine in moving a ton a mile under these conditions with the stored energy in the 19-100 of a pound of coal consumed in that service, it appears that 7 per cent of the stored energy of the fuel is converted into useful work. By the Searles' formula a very much higher economy is indicated. But the 7 per cent is itself an improbable value. Working tests skillfully planned and carefully made, of equally good non-compound engines, showed only 5½ per cent of the theoretic value of the fuel realized. Moreover, the 7 per cent comes too near the performance of the best stationary engines. I am indebted to Mr. J. D. Estabrook, C. E., for the result of a seven days' test of the triple expansion Schichau engine of 1,100-horse power now in the Washburn-Crosby Company's flouring mill at Minneapolis. This fine engine will be remembered by many who saw it in operation in Machinery Hall at the Columbian Exposition. The test was conducted by the late Prof. Wm. A. Pike and Prof. H. E. Smith, both of this college, and showed one indicated horse power for 1.928 pounds of Youghiogheny coal consumed, the coal having a determined calorific power of 13,222 B. T. U. Thus the engine developed in the cylinders 10 per cent of the theoretic value of the fuel. Deducting one-tenth from this result for engine friction, we see that no single

expansion locomotive can be held to realize 7 per cent economy without supposing that it comes well up to a triple expansion stationary engine in efficiency. I think the principal source of error here is not in the calorific value assumed for the fuel, but in the formula for train resistance. For high speeds both those named appear to give excessive results. Consequently, when we use either for high speed, the engine appears to be doing an amount of work that in reality it cannot get out of the coal. So the above approximation of 7 per cent net out of the fuel is only to be considered as suggestive, or as possessing a negative value in that it impugns the traction formulæ. In order to reach a result of greater value, conditions that I have assumed, such as the calorific power of the fuel, and the traction force exerted, would have to be determined by experiment.

However, as a rough check upon the foregoing, I cite the performance of English freight engines, as given by Mr. D. K. Clark, in his elaborate treatise on the steam engine, one of which moved a ton a mile by the consumption of 16-100 of a pound of coal and another 14-100. Of course the speed was here much lower, and the coal almost certainly better, and we have no account of the grades. Also, the Scotch Express, which makes about fifty miles an hour on the average, and mounts some long and heavy grades, is drawn by a compound engine that moves a ton a mile with two ounces of coal estimated to be 50 per cent better than ours, though it cannot be so much better than the coal above described. Again, the freight train statistics of the Chicago, St. Paul, Minneapolis & Omaha Railway Company for the years 1885 and 1895 show that the average performance of engines in each year was to move a ton a mile with 19-100 of a pound of coal. These results are based on the consumption of coal per mile run of engines in hauling 796,000 cars in the earlier year, and 978,000 in the later one, and therefore are deductions in which all kinds of train resistance are averaged.

But cost of fuel is only one item of engine expense, and heavy engines are costly in other ways. The repairs upon them are usually very expensive. Their fire-box plates are so severely tried by the fierce combustion, and by expansion and contraction, as to require frequent renewal. Strenuous endeavors are made to secure the best material for this purpose,

yet a sheet has been known to show more than 150 cracks after a short service. Also, the great weight of the reciprocating parts aggravates the destructive effect of a lack of balance in those parts, and consequently these monsters soon pound flat places in the tires of drivers, and must be sent to the shop to have those defects turned off. Their effect upon the rail will be mentioned later

An increase in the capacity of freight cars has kept pace with the growth of engines; the two are correlatives of a single development. This increase has worked an economy in heavy traffic because less dead weight proportionally is hauled. A car weighing 20,000 pounds carries 20,000 pounds; one weighing 22,000 carries 40,000; one weighing 29,000 carries 60,000. From 1865 to about 1876 nearly all freight cars were of the capacity of 20,000 pounds. The increase then began. On the road of which I have been speaking the average capacity of the freight car has increased twenty-five per cent in the last eleven years. But the Lake Shore & Michigan Southern, by the fullness of its reports, offers one of the most striking and useful illustrations of this economic tendency. This is a trunk line, so called, one of the main routes of traffic between the East and the West, on which the pressure of competition would naturally give a powerful stimulus to mechanical and engineering ingenuity. Also the movement indicated has been so long in operation with this company that it may be measured by results. Accordingly we find that the freight traffic of this road shows a growth in ton miles, between 1870 and 1895, of 318 per cent, due to an increase in train mileage of only 80 per cent, but in train loads of 132 per cent. The car equipment of this road also throws light on these changed conditions. Out of 18,700 freight cars, 5,700 carry 40,000 pounds each, 3,200 have 45,000 pounds capacity, 3,200 have 50,000 pounds capacity, and the remaining 6,600 are of 60,000 capacity. Many roads have special cars designed to carry exceptional loads. The Pennsylvania and the Northwestern have a number whose capacity is from 70,000 to 150,000, but these are not sufficiently numerous to further emphasize the tendency towards heavier loading. Nor is it likely that the movement will go further in the near future. Indeed, a reaction has already set in. Some managers have discovered the limited use of cars of great carrying capacity. Such cars are in

fact only suited to heavy through traffic, and a company may make the mistake, and some have made the mistake of putting too much money into this kind of rolling stock. A car of 50,000 pounds capacity, found in a local train, strutting as it were with a few boxes of soap, is an example of pride going before a fall; it is losing money for the company. The equipment should be adapted to the traffic. One source of loss in these cars of large capacity is that, especially on foreign roads, they stand idle a great part of the time because no suitable loads are offered.

In connection with the subject of dead weight, the steel car is likely to work an economy. One of these cars, that weighs 25,900 pounds, carries 80,000 pounds, as compared with a wooden car of the same weight that carries but 50,000 pounds. The principal objection made to this car is the conservative one that it is apt to prove costly to handle and repair after it is wrecked. But this implies that the accident is the rule and not the exception in car service. The objection may be overcome, and doubtless will be overcome, by improvements in design, whereby such cars can readily be taken to pieces. Then they may easily prove to be more economical in repairs than wooden cars, which so often are destroyed as to all but the iron in them.

With fewer trains passing over the road by reason of using more powerful engines, renewals of track repairs may be less costly. In short, out of a total of forty items of operating expenses, sixteen will be favorably affected by such a change to heavier engines, and many more will not be affected either way. On the other hand, there is to be charged against the improvement the increased cost of engine repairs and the interest cost of making the change in engines, track and bridges. Though the last two would by some companies be deemed betterments, and their money cost would be added to the cost of the road, yet interest on the amount must be earned if the assumed economy is justified. This is the general principle by which all such experiments are to be measured. For all our railroads have been built with borrowed money. The main end of the operating department must be, to earn interest on the bonds and a reasonable dividend on the stock. It is primarily the volume of traffic that does this, supposing, of course, that the business is conducted at a profit. Any specific

economy in operation will bear usefully on this result, but is of secondary importance compared with the volume of business. That this is true is shown by the fact that any particular economy, such for instance as the introduction of more powerful engines, will usually not be obvious on examining the general published statistics of most companies. Thus, it might be expected that the effect of introducing heavier rails, with heavier engines and cars of greater capacity upon them, would immediately be seen in the items of renewal of rails, cost of repairs of track, of repairs of engines, and in the percentage of operating expenses to gross earnings. But with a successful road fifteen hundred miles long such anticipated results will not often be realized; that is, the general statistics will not disclose the particular economy. And it is for the reason that the relatively small results are lost in the magnitude of the totals. They have, so to speak, only local bearing and significance. The accounts of the division on which heavy engines have displaced light ones may show that expenses have been reduced by the change in a degree justifying the experiment. But after all it is a complicated matter to balance the account between certain visible and incontestable savings, such as come from employing fewer engineers and firemen, and from a smaller consumption of coal in moving a given tonnage, on the one side, and on the other not only interest on the cost of additions to the property, but some expenses not at first readily determinable; as, for instance, whether the big engines will not pound themselves to pieces much faster than lighter ones, and whether they will not file away the rails and their own tires much faster than the others did. However, during the past twenty years the movement has been in the direction indicated, and so far as cost of rails is concerned is sustained by some general considerations.

If the weight of rails were to be increased from sixty-five pounds per yard to eighty, with corresponding fastenings, the increased cost of track at the present time would be about $1,400 a mile. If on a division two hundred miles long we add $20,000 to this for alterations in bridges, to enable them to carry the heavier loads, we shall have a total of $300,000, the yearly interest on which, at five per cent, would be $15,000. Now, such a division may be earning $3,000,000 annually, on which the interest charge for account of improved

track, as above given, would not be a burden, even in the extreme case that the heavier metal did not prove economical in connection with the heavier rolling stock. But on the other hand it may almost be decided without going into details, that an economy of $15,000 a year, can be worked in operating expenses amounting to $1,800,000 by the purely administrative reforms continually being introduced. Thus there is a margin of opportunity for the experiment; besides which are the possibly longer life of the rail, fewer track repairs, the saving of fuel on the large engines, and in the wages of trainmen, leaving some other items doubtful. So far then as this movement has proceeded, it seems justified by general prudential considerations.

The further question arises, what is the rational limit of this economy? How long can we go on, increasing the weight of engines and cars and loads on the present quality of metal? The chief limiting fact would seem to be the ductility of the rail. It will not do to use a brittle rail, but on the other hand the soft steel now used flows under the cold rolling given it by the heavy wheel loads. Rails give out partly by wear and partly by deformation. On the outside of curves they are rendered unserviceable as much by the latter cause as by the former. In some of the new engines each seventy-three inch driver presses on the rail with a weight of over 20,000 pounds, and it was shown by Mr. Chanute's experiments that with 14,000 pounds on a five-feet driver the small area of contact indicated a pressure in excess of the elastic limit of the steel. So also these great machines, with the larger wheeels but heavier loads, are certainly very destructive of the rails, first by grinding them, and again by squeezing them out of shape much in the manner that they were originally shaped. These results may easily be observed in large yards, where the inside of many railheads will be found worn away to the splices, the outside of them showing at the same time a projecting lip formed by excessive pressure. It is obvious that increasing the depth and weight of the rail has its principal effect in strengthening it as a girder, to carry the load from tie to tie, and does not prevent the head from yielding outwardly under pressure. Therefore we must proceed cautiously if we further increase the load on the rail, carefully balancing the account between maintenance of way and movement of traffic. This

may involve a more minute distribution of expenses than has been customary heretofore. On the Lake Shore road, before mentioned, the item of renewal of rails is about one per cent of the income. Expressed in dollars it is a large sum, but the small percentage shows that wear of rails is not a place in which large economy can now be hoped for. It is the place where expense is most certainly proportional to use, since it depends almost wholly on the number of trains run over the rails. There is therefore less chance here for waste or extravagance than in any other branch of operating expenses.

Supposing the limit to have been now nearly reached in adapting the weight of engines to Bessemer rails, I think we may look to see future economies take one of two directions. The first is in the line of a better rail, either of steel possessing greater durability in this kind of service, or of some alloy offering higher resistance to wear and distortion than this steel, yet sufficiently ductile to be rolled and to prevent brittleness. Our ordnance officers are dealing with a similar problem, namely, to increase the power of guns without increasing their weight, for which they need a metal for the inner barrel that will resist the erosive action of gases at high pressure better than the steel now used is found to do. The invention of Bessemer metal was due to Sir Henry Bessemer's desire to obtain a better metal for ordnance. He knew little or nothing of metallurgy when he began his experiments, which resulted in revolutionizing the steel industry of the world. It is therefore not unreasonable to expect that a better rail, for which there will be, perhaps for ages, an ever-increasing demand, will be forthcoming. Bessemer rails, superior as they are compared to iron ones, may yet be the first windfall of a tree that is to yield better fruit. As a mere hint, I may allude to the possibility of cold-rolling the rails in manufacture.

The other direction in which I think we may look to see economy operate, on the supposition that wheel loads are now at a profitable maximum and that we must continue to rely on our present rail material, is in the use of more frequent but lighter and faster trains. The problem always is and will be to administer a railway most profitably. Accordingly, we must keep in view the fullest utilization of the property and not lose sight of the fact that an idle railroad not only is earning nothing, but is decaying and disintegrating as a physical

structure. When we reflect on how small a part of each day any particular rail in the line of this vastly expensive railroad actually is used in transportation, and earning something, the possibilities of traffic enlarge upon us. We then see the bearing of the idea of trying to work economy by more and faster trains in place of fewer and slower ones; of thus securing a greater average daily movement of freight cars, now surprisingly low; in short, of making time more an element of profit throughout the service, as now it only is in respect to passenger trains, to some few articles of perishable freight, and to the carrying of cattle. A street railway in a populous city illustrates the opposite tendency to that observed in recent steam railway management, for there we see cars or trains in sight one from another, the rails kept almost continually warm by the friction of use, thus realizing the foregoing ideal of a productive property. Circumstances have made our practice very unlike the European in respect to train service, but I think we may look to see changed social conditions, due to denser population and a fall in wages, bring in a similar economy.

Among the most remarkable facts of our subject is the constancy of the ratio of operating expenses to income on railroads in general. On the Lake Shore & Michigan Southern the average for the last twenty-five years has been 65 per cent, with but one very marked fluctuation. On the Chicago, St. Paul, Minneapolis & Omaha Railway it has been practically stationary at 64 per cent for the last fifteen years. On the first mentioned road the economies that we have outlined were long ago in full operation; on the latter they are not yet so completely developed. These facts seem to show two things of interest: First, that the proportional cost of operating a particular road is remarkably constant under all circumstances; and, second, that all railway improvements, not only betterments, but also those which make for economy of operation, inure to the benefit of the public. The most prosperous roads have only paid interest on their bonded debt and a fair dividend to stockholders. All the rest of their earnings have gone to the public, largely in the way of improved and cheapened transportation. I think we may infer from this stability of the relation of expenses to earnings that fast, light freight trains may be substituted for slow heavy ones without loss to

the companies, but with a growing profit due to more rapid circulation of commodities; and that this will prove true, notwithstanding the theoretical, and indeed actual cost of increasing speed.

Another direction which economy of operation has recently taken is toward loading engines to their full hauling capacity. Until within a short time the rule was to load them with the number of cars that the engineer said he could take up the limiting grade. This made the rule sometimes coincide with the caprice of the engineer. If on approaching the ruling grade he told the conductor that two cars must be dropped, they were accordingly set on the siding, to wait there till some other engineer would not rail at the suggestion of picking them up. While this system was in operation, an examination of way-bills often disclosed that the number of cars in the train was sufficient fully to load the engine if the cars had been fully loaded, but that in reality the train load was far too light for the engine because of cars very lightly loaded. All this has now been changed to great advantage by adopting what is called tonnage rating. Under this system the traction of locomotives has been determined experimentally and the proper loading has been derived from the results. To this end a freight engine is tested on the controlling grade of each of the sections into which the division is naturally divided by the existence of such grades. This engine is run up the grade at a proper speed, say twelve miles per hour, with a sufficient number of loaded cars of various known weights to stall it. Then an assistant engine goes behind and helps the train to start up again and acquire a speed of five or six miles an hour, when the helper drops off with one or two cars, and thus another trial is made, and so on till the load in tons that the engine can surely take up the grade is practically determined. On each hard spot in the division, caused by grades or by grades and curves combined, the engine is similarly tried; and then small deductions are made from the maximum loads so found to allow for specially long grades, such as tax the steaming capacity of engines.

An engine having been thus tested on the governing grades, and its performance recorded, one engine of each of the remaining classes in service is then tried similarly on one or two of the same grades and its relative power thus deter-

mined. This relative performance affords the rule for loading engines of these classes proportionally to their developed capacity. Thereafter all loading is by tons instead of cars.

In preparing the rating sheet to govern engineers under this system, some superintendents make three ratings, corresponding to three assumed conditions of weather and rail, while others rely on the discretion of the engineer to make deviations from the printed single ratings based on the trial conditions, at the same time holding him accountable for satistory engine performance. The tons hauled and coal consumed by each engine are bulletined monthly, and the engineers are found anxious to make good records by hauling full train loads. The economy thus effected is considerable. It has increased the train load from ten to twenty per cent on several roads whose officers have kindly given me their results.

Still another way in which economy has been worked in recent years is by reducing grades and curvatures. Most of our Western roads were originally located with an eye to facility and economy of construction, by the eye of the promoter rather than that of the engineer. They were what is called surface roads, conforming closely to the slopes of the country with their grades, and to the plan of the hills with their curves. Heavy grades and sharp curves and combinations of both marked this era. Many companies have recently spent large sums in improving these defective pieces of alignment, which were originally due to poverty of resources, and did not reflect on the intelligence of the engineer. To reduce a maximum grade is equivalent to increasing the capacity of engines. The equation is between the cost of operating the line as it is, and interest on the cost of the improvement, and as to all very bad places there can be no doubt that the betterment will be justified by events. It is largely by such works as these that lines geographically well placed are making their future prosperity secure against the competition of inferior lines, while by the same stroke they are reducing the cost of service to the public.

But of all causes that have contributed to economy of operation, the consolidation of short lines into large systems has been the most effective. Twenty years ago a thousand miles under one management was a giant railway. Now we see from five thousand to eight thousand miles in one system,

often practically controlled by a single administrative officer. Such a combination of interests and of utilities has reduced order out of chaos, estabished long periods of peace where there was continual war, and has given greater stability to private enterprise in the districts so served, because such a great system possesses an inertia comparable to that of a planet in its orbit, which hardly any force can disturb. The result is a development peculiar to this form of human activity under freedom. Under free competition the result is what we see, what no man could have foreseen or forestalled: it is that we have the best and cheapest service in the world.

I omit many minor economies, only intending to present a broad outline. It is for you who are soon to take possession of the field of engineering to be alive to the opportunities and requirements of this so learned profession. We have an enormous country, nearly the whole of it still undeveloped as compared with the wealthiest parts of Europe. We have one mile of railroad to eighteen of area, as compared with one to less than four in Belgium. Our mileage is almost sure to be doubled in your lifetime. Yet this is only one branch of engineering, and each of the others presents as wide a prospect. There is therefore every incentive to your ambition. You have but to read the story of Aladdin as a parable. Every man is born with an enchanted lamp of mental aptitudes. His fortune depends on his keeping it burnished.

As a last word, I should like to lodge in your memory the counsel of one of the great men whose names adorn the roll of the profession. Tyndall was a practicing engineer before he shone out as a philosopher. Speaking of his having failed in tens of thousands of experiments to wring a certain truth from nature (a struggle in which, however, he was finally successful), he gives this advice to young men:

"The experimenter, and particularly the young experimenter, ought to know, that as regards his own moral manhood, he cannot but win if he contend aright. Even with a negative result, the consciousness that he has gone to the bottom of his subject, as far as his means allowed—the feeling that he has not shunned labor, though that labor may have resulted in laying bare the nakedness of his case—reacts upon his own mind, and gives it firmness for future work."

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